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THE DOE-2 BUILDING ENERGY ANALYSIS COMPUTER PROGRAM

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ABSTRACT

Concern with energy conservation requirements has resulted in a growing awareness throughout the architectural/engineering community of the need for an easy-to-use, fast-running, completely documented, public-domain computer program for the energy-use analysis of buildings. DOE-2 has been developed to meet these needs. The program emphasizes ease of input, efficiency of computation, flexibility of operation, and usefulness of output. A key factor in meeting these requirements has been achieved by the development of a free-format Building Design Language (BDL) that greatly facilitates the user's task in defining the building; its heating, ventilating, and air conditioning (HVAC) systems; and its operation. This paper describes the DOE-2 program.

A. INTRODUCTION

Approximately one-third of the total energy consumed in the United States is used to operate buildings. Only by the efficient use of energy in each building will we reduce our energy consumption at local and, eventually, national levels. Saving energy in buildings will require new public policies, new building codes, and innovations in the design of buildings and communities. It will also require new design procedures and tools for engineers and architects, correct operation of building energy systems, and careful attention to the quality of materials and construction.

Until recently, building designers lacked the necessary tools for the comprehensive calculation of dynamic heating and cooling loads, the simulation of heating and cooling distribution systems, the modeling of equipment supplying the required energy, and the calculation of the life-cycle costs of owning and operating building energy systems. Calculation of the response of building envelopes and systems to time-dependent variations of heat and moisture resulting from the weather outside and human activity inside is practical only with the aid of a computer. Earlier energy analysis computer programs have had limitations: they have been expensive to run, difficult to use, or limited in scope. Furthermore, differences in algorithms and assumptions may cause different programs to give widely differing results.

Therefore, there was a need for an easy-to-use, fast-running, well-documented, widely available computer program for the analysis of energy use in buildings. In response to this need, three national laboratories collaborated to develop a new computer program for design, analysis, research, and code compliance. Lawrence Berkeley Laboratory (LBL), as the lead laboratory, collaborated with the Los Alamos Scientific Laboratory (LASL) to develop the DOE-2 program. DOE-2 is an improved version of the former DOE-1 program, which itself is an improved, updated version of the former Cal-ERDA program. The Argonne National Laboratory and Consultants Computation Bureau were collaborators with LBL and LASL on Cal-ERDA and DOE-1.

The DOE-2 LOADS routines are based on American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) algorithms.(1,2) The primary and secondary systems simulation routines are based on algorithms developed by Consultants Computation Bureau in the early 1970's.

B. DESCRIPTION

DOE-2 can simulate hour-by-hour performance of a building for each of the 8760 hours in a year. Input is facilitated by a newly developed computer language, called the Building Design Language (BDL), whereby the user instructs the computer in familiar English terminology. DOE-2 also provides a means of performing the complicated analysis of energy consumption without the necessity of preparing input to the program that is correct in every minor detail. A set of default values (numbers used for the value of a variable if the user does not assign one) is included to reduce the amount of input that must be supplied to run the program.

Figure 1 shows a brief organizational configuration of the DOE-2 computer program. A detailed description of an earlier version of DOE-2 is found in Ref. 3.

DOE-2 has four simulation subprograms. These are executed in sequence, with the output of one becoming the input to the next. The function of each subprogram is summarized below.

1. <u>LOADS Subprogram</u>

The LOADS subprogram calculates the hourly heating and cooling loads, using primarily the algorithms described in Ref. 1. DOE-2 provides a reorganization and reprogramming of many of these algorithms to increase execution speed.

In the LOADS subprogram, the heat gains and losses through walls, roofs, floors, windows, and doors are calculated separately. Heat transfer by conduction and radiation through the building skin is computed, using response factors, considering the effects of the thermal mass; placement of insulation; sun angle; cloud cover; and building location, orientation, and architectural features. Infiltration loads can be calculated on the basis of the difference between the inside and outside conditions and on an assumed leak rate (crack method), or by an air-change method.

Internal use of energy for lighting and equipment is also computed according to schedules assigned by the user for each piece of equipment that affects the energy balance of each space. The latent and sensible heat given off by the building occupants are calculated as an hour-by-hour function of the occupancy of the building.

All the LOADS computations are performed on the basis of a fixed temperature for each space as specified by the user. Because the LOADS program calculates thermal loads on the basis of hourly weather data using

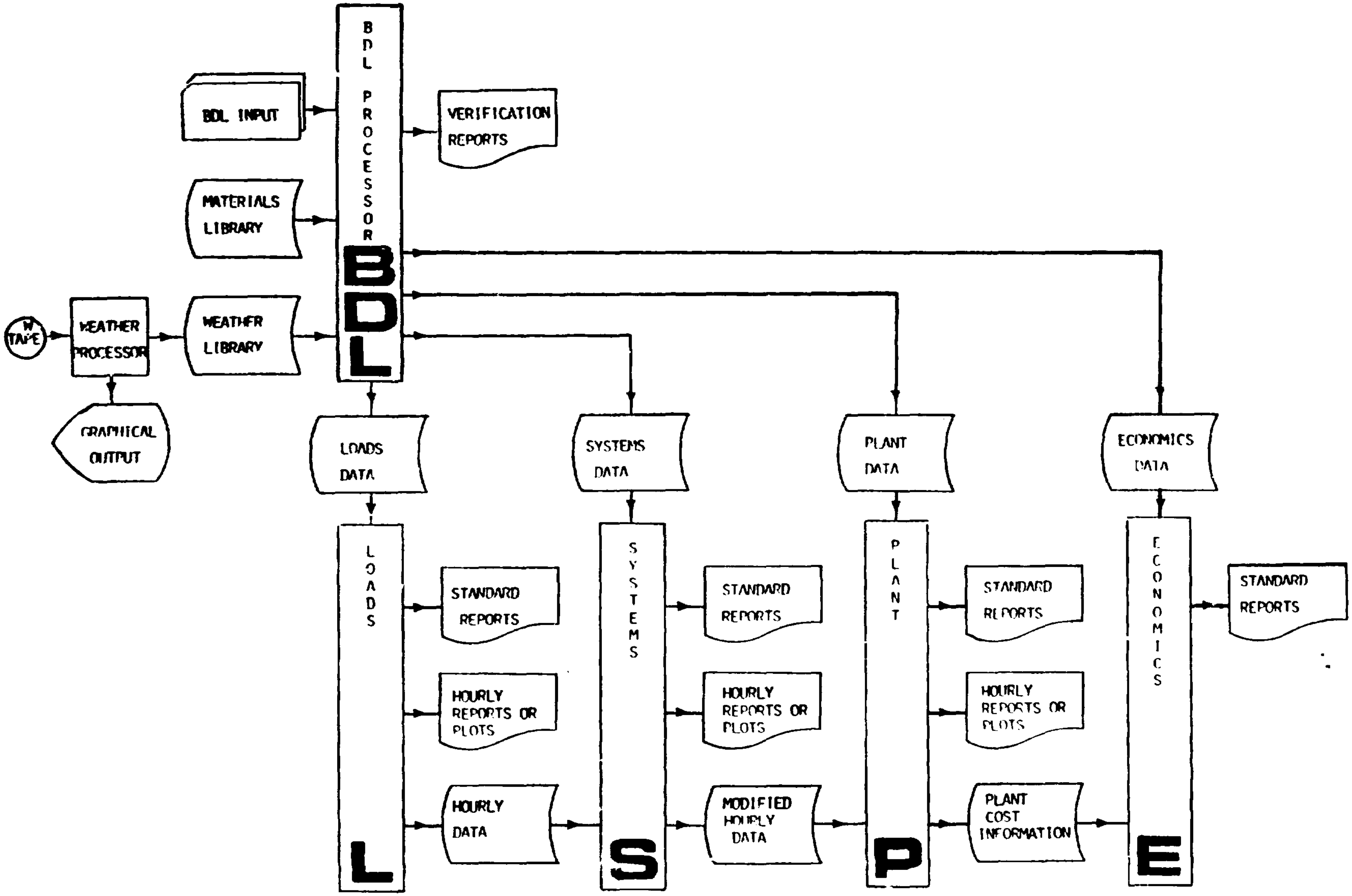

Fig. 1. DOE-2 Computer Program Configuration

artificial (fixed) space temperatures, the output may have little bearing on the actual thermal requirements of a building. It is, instead, a baseline profile of the thermal performance of a space, given a fixed internal temperature. The SYSTEMS program then modifies the output of the LOADS program, to produce actual thermal loads based on an hourly variable internal temperature.

2. SYSTEMS Subprogram

The SYSTEMS subprogram contains algorithms for simulating performance of the secondary HVAC equipment used to control the temperature and humidity of each zone within the building. Many of the equations used to develop the SYSTEMS simulation procedure are given in Ref. 2. These algorithms have been organized and coded to allow selection of one of 16 preprogrammed space-conditioning systems. The SYSTEMS subprogram is used by choosing one of these preprogrammed systems and providing the necessary input data for the simulation calculations. New subroutines, which can be developed and entered by the user, are necessary for study of a system that has not been preprogrammed.

The SYSTEMS subprogram uses the output information from the LOADS program and a list of user-defined system characteristics (e.g., air-flow rates, thermostat settings, schedules of equipment operation, or temperature setback schedules) to calculate the hour-by-hour energy requirements of the secondary HVAC system. The SYSTEMS subprogram calculates thermal loads based on variable temperature conditions for each zone.

3. PLANT Subprogram

The PLANT subprogram contains the equations necessary to calculate the performance of the primary energy conversion equipment. The operation of each plant component (e.g., boiler, absorption chiller, compression chiller, cooling tower, hot water storage tank, and solar heater) is modeled on the basis of operating conditions and part-load performance characteristics. The user selects the type of plant equipment to be modeled, the size of each unit, the number of units, and the number of units simultaneously available. Values for equipment lifetime and maintenance may also be entered if preprogrammed values for these variables are not used. The sequence of equipment operation may be specified as a step function of the load. The user may schedule equipment operation by time (hourly or seasonally) or by peak load schedules. The PLANT subprogram uses hourly results from the LOADS and SYSTEMS subprograms and the user's instructions to calculate the electrical and thermal energy consumption of the building. The DOE-2 PLANT subprogram also contains subroutines for computing the life-cycle costs of plant equipment.

4. ECONOMICS Subprogram

The ECONOMICS subprogram may be used to compute the life-cycle costs of various building components and to generate investment statistics for economic comparison of alternative projects. The methodology used is similar to that recommended by the Department of Energy for evaluation of proposed energy conservation projects.(4)

In addition to these simulation subprograms, DOE-2 contains various report-generating routines that print hourly values of selected variables over specified intervals. There is also a Weather Data Processor that allows extraction, editing, and display of hourly weather data from weather tapes.

Finally, DOE-2 contains two computerized libraries that can be accessed by the user from the program using BDL. The first, a materials library, contains thermal data for different materials commonly used in walls, roofs, and floors. The second, a weather library, contains hourly weather data for 75 locations in the United States. (With the DOE-2 Weather Data Processor, the user can easily add other locations to this library.)

C. BUILDING DESIGN LANGUAGE

The four subprograms called LOADS, SYSTEMS, PLANT, and ECONOMICS, are indicated by L, S, P, and E, respectively, in Fig. 1. The input to these programs is provided by using BDL. The information given by the user through BDL is processed by the BDL Processor Program and fed into the L, S, P, and

E data files in appropriate form. Thus, BDL, as a problem-oriented language, assists the user in communicating with the simulation programs.

The BDL Processor checks each BDL instruction for proper form, syntax, and content. The BDL instructions are read sequentially, and each is examined to determine whether any BDL commands or keywords have been used and if values have been assigned. The BDL Processor also checks for values that are beyond the expected range for input variables. If values are not specified, the BDL Processor assigns an assumed (default) value, which will appear in the listing of input data. The BDL Processor also collects whatever data the user desires from the various permanent libraries (e.g., data from the Materials Library). Response factors, three series of numbers that are used to determine the transient flow of heat through exterior walls and roofs as they react to randomly fluctuating climatic conditions, are also calculated by the BDL Processor for use by the LOADS and SYSTEMS subprograms. The BDL Processor also prepares the input data files for use by the LOADS, SYSTEMS, PLANT, or ECONOMICS (LSPE) subprograms.

For different types of users, there may be a variety of problem sizes and a wide spectrum of detail required. The problems may range from very detailed consideration of heat transfer through a single wall to a gross model of an entire building as a single zone. In responding to the challenge of this complexity, BDL simplifies the energy analysis of buildings without compromising the flexibility required for different levels of detail.

BDL has the following features:

- <u>BDL uses engineering language</u>. The input is entirely in the language of the engineers using BDL. No conventional programming experience is necessary to describe a problem or to interpret the results.
- <u>There are no rigid input formats</u>. Input data can be specified in any form convenient to the user. In other words, BDL is designed with the engineer, and not the keypunch operator, in mind.
- <u>The sequence of input is flexible</u>. The user has the freedom to specify the sequence of input best suited for each individual problem.

- <u>The language is efficient</u>. Because no two problems are ever expected to be exactly alike, the user can specify the input so that BDL executes it as if it were a special purpose program written for that one particular problem. The processing of small problems is not penalized by BDL's ability to process large problems.
- <u>Parametrics are easily accomplished</u>. A parametric study can be performed in a single run simply by adding a few cards to the input deck.

D. APPLICATIONS

DOE-2 can be used to study a large range of energy-conserving possibilities, including

(1) Effect of the thickness, type, and relative position of insulation in exterior walls and roofs;
(2) Effect of occupant, lighting, and equipment schedules;
(3) Evaluation of intentionally undersized primary HVAC systems by calculating the room temperature and humidity deviations from a design set point;
(4) Effect of intermittent operation such as the shutdown of HVAC systems during the nighttime or on weekends;
(5) Effect of reduction in outside air requirements and use of outside air for cooling;
(6) Effective use of internal and external shading;
(7) Off-peak heating or cooling of buildings to shave peak heating or cooling demands; and
(8) Use of solar energy for heating and cooling.

DOE-2 can be used profitably in many stages of decision-making, including

(1) Predesign selection of the basic elements of the building, primary and secondary HVAC systems, and energy source;

(2) Evaluation, during the design stage, of specific design concepts and modifications;
(3) Evaluation, during construction, of contractor proposals for deviations from the construction plans and specifications;
(4) Analysis of existing buildings for cost-effective retrofits; and
(5) Analysis of electric load management techniques.

E. TESTING AND VERIFICATION

The algorithms used in DOE-2 are being systematically tested by comparing program results with detailed hand calculations. In addition, a project is under way to verify DOE-2 against measured energy-use data from actual buildings.[5]

F. DOCUMENTATION

The DOE-2 Users Guide[6] is an instructional introduction to the program, while the DOE-2 Sample Run Book[7] contains detailed sample program runs for a variety of building types. A DOE-2 BDL Summary,[8] which contains a summary of all BDL commands and keywords, has also been prepared. These three documents were prepared by LBL. The DOE-2 Reference Manual[9] describes BDL in detail, and the DOE-2 Program Manual[10] describes the algorithms used in the programs and contains flow charts of the subroutines. Both of these manuals were prepared by LASL.

All of the above documents will be available in mid-April 1979 from the National Technical Information Service (NTIS), US Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

G. ACKNOWLEDGMENT

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